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Effects of Fluid Distribution on Measured Geophysical Properties for Partially Saturated, Shallow Subsurface Conditions

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DISCLAIMER

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FY2002 Final Report for EMSP Project #70108

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Research Objective

Our goal is to improve geophysical imaging of the vadose zone. We are achieving this goal by providing new methods to improve interpretation of field data. The purpose of this EMSP project is to develop relationships between laboratory measured geophysical properties and porosity, saturation, and fluid distribution, for partially saturated soils. Algorithms for relationships between soil composition, saturation, and geophysical measurements will provide new methods to interpret geophysical field data collected in the vadose zone at sites such as Hanford, WA.

Research Progress and Implications

This report summarizes work after 32 months of a 3-year project. We modified a laboratory ultrasonics apparatus developed in a previous EMSP project (#55411) so that we can make velocity measurements for partially-saturated samples rather than fully-saturated or dry samples. Modifications included adding tensiometers and changing the fluid system so that pore fluid pressure can be controlled and capillary pressure can be determined. We made a series of measurements to determine properties of partially saturated Ottawa sand and Santa Cruz aggregate samples as well as sand-clay samples and some preliminary measurements on natural soils. Current measurements include investigations of effects of pore fluid chemistry on grain cementation and velocities for calcite-cemented sand samples. We analyzed these measurements as well as velocity and electrical properties measurements made as part of the earlier EMSP project and developed relationships between measured geophysical properties and parameters of interest, including lithology, fluid content and distribution, and soil microstructure. Recent research results have been presented in journal papers and at several EMSP program reviews and scientific conferences (see list of publications below), including at a special session that the lead principle investigator organized at the 2002 Symposium on the Application of Geophysics to Engineering and Environmental Problems, held in Las Vegas in February 2002. Additional results from current measurements will be presented at the American Geophysical Union Fall Annual Meeting in San Francisco in December, 2002, at a special session organized by the lead principle investigator. Recent results of this project have been useful for improving the understanding of seismic measurements published in the literature. Our laboratory velocity measurements have confirmed recent field observations of extremely low

seismic velocities of a few hundred m/s in shallow soils, and we have shown that these values are consistent with effective medium theories. We have shown that the laboratory velocities for partially saturated sands, collected at ultrasonic frequencies, behave as predicted by Gassmann's static result, and thus laboratory ultrasonic velocities can be considered analogous to velocities at seismic frequencies. We have shown that shallow soils may have very steep velocity gradients, a matter of some importance for seismic field data that are interpreted using ray-tracing codes that may assume straight, rather than curved, ray paths. We have also found that packing effects can be important, and this will be significant for seismic surveys conducted using hammer sources since the properties of the soil below the plate could change after repeated hammer blows. The presence of clay reduces the nonlinearity, and this may be apparent in seismic field data. We found that Vp/Vs ratios are a useful indicator of clay content, particularly when considering changes with depth. We were able to apply self-consistent and differential effective medium theories to understand velocities in sandy soils with relatively low concentrations of clays or organic materials, but for concentrations above about 20 percent we had to use theories that included grain contact effects. A new method was developed for relating compressional and shear wave velocities to fluid content and distribution, and tests on laboratory data were successful. It would be useful to test whether this new technique can be used to investigate fluid distribution in the vadose zone using seismic data. Our results suggest that the approach for this EMSP research project has been appropriate, that microstructure is an important factor for measured geophysical properties, and that seismic field experiments should be designed to collect both compressional and shear wave velocity data and to collect wave amplitude as well as velocity information when possible. The lead p.i. has written a new EMSP proposal in collaboration with Ernie Majer of LBNL for a new project that would involve collecting seismic data at appropriate sites including Hanford and applying these new interpretation techniques to the data to further develop the methods.

Planned Activities

We plan to continue making laboratory measurements of compressional and shear velocities of soils while studying effects of pore fluid chemistry on cementation and velocities, for the rest of this summer. Final results of this last part of the work will be presented at the Fall Annual Meeting of the American Geophysical Union, as mentioned above. This is the final year of this project and all results have been published or presented at scientific conferences and EMSP program meetings. If the new EMSP project with Ernie Majer of LBNL is funded, results from this project will be used to interpret the seismic field data collected for the new project. Those results will be shared with other interested current and former EMSP and EM project P.I.'s (e.g., C. Carrigan, LLNL; Jil Geller, LBNL; D. Steeples, U. Kansas; R.J. Knight, Stanford/U. British Columbia).

Information Access

Copies of many of these documents may be viewed online or downloaded at the URL
http://www.llnl.gov/tid/lof/
by performing a search using the UCRL number of the document or the author name.

Berge, P. A., 2001, Modeling Compressional and Shear Wave Velocities of Unconsolidated Sediments in the Vadose Zone: *LLNL report UCRL-JC-145245-ABS, Eos, Transactions of the American Geophysical Union, Fall Meeting Supplement, Proceedings of the Fall Annual Meeting, held in San Francisco, CA, Dec. 10-14, 2001,* **82**, F326-327.

Berge, P. A., Bonner, B. P., Roberts, J. J., Wildenschild, D., Berryman, J. G., and Bertete-Aguirre, H., 2001, Status and Recent Results for EMSP Project #70108, Effects of Fluid Distribution on Measured Geophysical Properties for Partially Saturated, Shallow Subsurface Conditions: *LLNL report UCRL-JC-145937 and UCRL-PRES-145937,* presented at the *FY2002 EMSP Vadose Zone Principal Investigator Workshop, sponsored by DOE EMSP and by PNNL, Nov. 5-6, 2001, Richland, WA.*

Berge, P. A., and Bonner, B. P., 2002, Seismic velocities contain information about depth, lithology, fluid content, and microstructure: *UCRL-JC-144792*, proceedings of the *Symposium on the Application of Geophysics to Engineering and Environmental Problems, Las Vegas, NV, Feb. 10-14, 2002, sponsored by the Environmental and Engineering Geophysical Society,* also submitted to the *Journal of Environmental and Engineering Geophysics*.

Berryman, J. G., 2001, U. S. Patent No. 6,269,311: Issued for ``Discrimination of Porosity and Fluid Saturation Using Seismic Velocity Analysis," to J. G. Berryman, on July 31, 2001.

Berryman, J. G., Berge, P. A., and Bonner, B. P., 2002, Estimating rock porosity and fluid saturation using only seismic velocities: *LLNL report UCRL-JC-135507, Geophysics*, **67**, 391-404.

Bertete-Aguirre, H., Berge, P. A., and Roberts, J. J., 2001, Imaging Simulated Field Data for Electrical and Mechanical Properties of Shallow Environmental Sites: *LLNL report UCRL-JC-145242-ABS, Eos, Transactions of the American Geophysical Union, Fall Meeting Supplement, Proceedings of the Fall Annual Meeting, held in San Francisco, CA, Dec. 10-14, 2001,* **82**, F326.

Bertete-Aguirre, H., and Berge, P. A., 2002, Recovering soil distributions from seismic data using laboratory velocity measurements: *LLNL report UCRL-JC-141559, Journal of Environmental and Engineering Geophysics*, **7**, 1-10.

Bertete-Aguirre, H., Berge, P. A., and Jeffery J. Roberts, 2002, Using laboratory measurements of electrical and mechanical properties to assist interpretation of field data from shallow geophysical measurements: proceedings of the *Symposium on the Application of Geophysics to Engineering and Environmental Problems, Las Vegas, NV, Feb. 10-14, 2002, sponsored by the Environmental and Engineering Geophysical Society*, also submitted to the *Journal of Environmental and Engineering Geophysics*.

Bonner, B. P., Berge, P. A., Aracne-Ruddle, C. M., Bertete-Aguirre, H., Wildenschild, D., Trombino, C. N., and Hardy, E. D., 2000, Linear and nonlinear ultrasonic properties of granular soils: *LLNL report UCRL-JC-136207*, presented at the *Materials Research Society Spring Meeting, Symposium BB, April 24-28, 2000, San Francisco, CA,* also in Sen, S., and Hunt, M. L., Eds., *The Granular State, Materials Research Society Symposium Proceedings,* **Vol. 627,** BB3.7.1-BB3.7.6, 2001.

Bonner, B. P., Berge, P. A., and Wildenschild, D., 2001, Compressional and shear wave velocities for artificial granular media under simulated near surface conditions (expanded abstract): *LLNL report UCRL-JC-142935, Technical Program of the Society of Exploration Geophysicists International Exposition and Seventy-First Annual Meeting, Sept. 9-14, 2001, San Antonio, TX,* **Vol. II**, 1419-1422.

Prasad, M., Zimmer, M., Bonner, B. P., and Berge, P. A., 2002, Measurement of velocity and attenuation in shallow soils: *UCRL-JC-145238*, submitted to be included as a chapter in *Near-Surface Geophysics, Applications and Case Histories, Vol. II,* Butler, D. K., ed., Society of Exploration Geophysicists, Tulsa.

Toffelmier, D., W. Dufrane, C. Aracne-Ruddle, B. P. Bonner, P. A. Berge, B. Viani, and K. Knauss, 2001, Load Dependence of Ultrasonic Velocities for Sand and Sand / Clay Mixtures: *LLNL report UCRL-JC-145264-ABS, Eos, Transactions of the American Geophysical Union, Fall Meeting Supplement, Proceedings of the Fall Annual Meeting, held in San Francisco, CA, Dec. 10-14, 2001,* **82**, F326.

Wildenschild, D., 2001, Using CMT to determine gas- and liquid-phase distributions in porous media: Advanced Photon Source Research Highlight, Argonne National Laboratory, at the URL www.aps.anl.gov/apsimage/porousmediamain.html

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